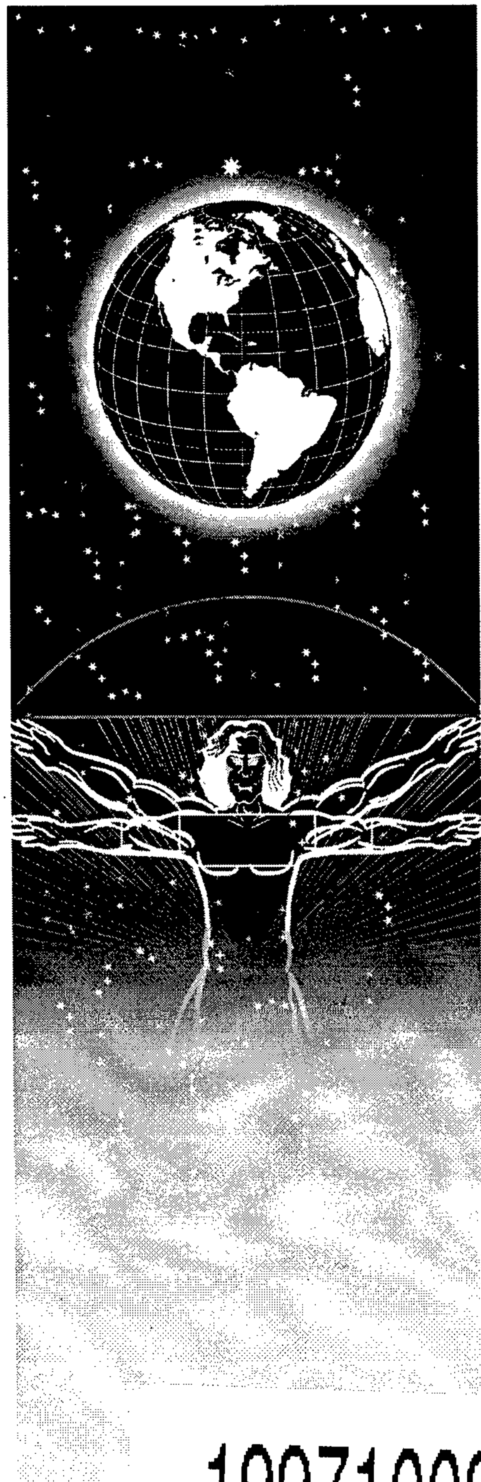
AL/HR-TP-1996-0027



UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

IICE Technology Transition Effort For E-3 Programmed Depot Maintenance (PDM)

Michael Painter
Mike Graul
Charles Marshall

KNOWLEDGE BASED SYSTEMS, INC
One KBSI Place
1500 University Drive East
College Station, Texas 77845

James C. McManus

ARMSTRONG LABORATORY
Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB OH 45433 7604

October 1996

Approved for public release; distribution is unlimited

Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB OH
45433-7604

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation, or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

James C. McManus

JAMES C. McMANUS
Contract Monitor

Robert P Johnson

for BERTRAM W. CREAM, Chief
Logistics Research Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1996

3. REPORT TYPE AND DATES COVERED
Final - Feb 91 to Sep 95

4. TITLE AND SUBTITLE
IICE Technology Transition Effort for E-3 Programmed Depot Maintenance (PDM)

5. FUNDING NUMBERS
C - F33615-90-C-0012
PE - 63106F
PR - 2940
TA - 01
WU - 08

6. AUTHOR(S)
Michael Painter Charles Marshall
Mike Graul James C. McManus

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Knowledge Based Systems, Inc.
One KBSI Place, 1500 University Drive East
College Station, TX 77845

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB, OH 45433-7604

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/HR-TP-1996-0027

11. SUPPLEMENTARY NOTES

Armstrong Laboratory Technical Monitor: James McManus, AL/HRGA, DSN 785-8049

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document reports the results of a technology demonstration effort targeted at supporting Air Logistics Center (ALC) Programmed Depot Maintenance (PDM) planning and scheduling needs using advanced technologies from the Armstrong Laboratory Information Integration for Concurrent Engineering (IICE) project. The most visible product developed was a prototype planing system for E-3 PDM called ProPlan. ProPlan is an open architecture, client/server system with embedded Commercial Off-The-Shelf (COTS) software that provides a user-friendly, single-point source of data to E-3 planners. Another product, the Stochastic Resource Requirements Projector (SRRP), uses the planning data stored in ProPlan to provide users with a self-maintaining PDM simulation model support multi-aircraft schedule feasibility testing, contingency planning, and finite-capacity schedule generation. A prototype E-3 shop floor data collection database was also developed, together with a set of screens and reports characteristic of the E-3's shop floor information system needs. Testing of the ProPlan prototype was accomplished by Air Force personnel at OC-ALC.

14. SUBJECT TERMS
IDEF
Integration
Information engineering
Logistics
Method
Methodology
Planning
Simulation
Software
Systems engineering

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Promising research results from AL/HRGA's Information Integration for Concurrent Engineering (IICE) program prompted Armstrong Laboratory management to expand the scope of planned IICE technology demonstration and testing activities to include their application to the Air Logistics Center (ALC) environment. The Oklahoma City Air Logistics Center (OC-ALC), located at Tinker Air Force Base (AFB), Oklahoma, was chosen as the site for this work. As one of the five major ALCs within the Air Force, Tinker AFB offered a unique environment for fully testing, under Armstrong Laboratory management, the effectiveness, robustness, and scalability of the emerging IICE technologies.

The intent of the work reflected in this report was to leverage IICE advanced developments in direct support of OC-ALC Programmed Depot Maintenance (PDM) planning and scheduling needs. The results of this work revealed both the ease and effectiveness with which the IICE technology can be brought to bear on a situation, and the further potential that this technology and its application provide.

INTRODUCTION

Global economic pressures and the perception that our nation no longer needs a large military production base have motivated downsizing measures and conversion strategies aimed at sustaining military readiness while simultaneously improving competitiveness in the global commercial arena. For OC-ALC, these changes have implications for both their way of doing business and the size and composition of their workforce.

From an enterprise operations perspective, OC-ALC is faced with the challenge of evolving from a "just-in-case" environment, for which the ALCs were originally designed, to an environment that manifests the new "just-in-time" economy. That is, OC-ALC is being challenged to demonstrate their cost, on-time delivery, and quality performance in a more highly charged, competitive environment. Even large end-item maintenance workload, previously the sole purview of the ALCs, has begun to be challenged in open commercial competition. For example, at Tinker AFB, a significant percentage of the E-3 Programmed Depot Maintenance (PDM) workload was competed for—the potential first of many future commercial contracts. Having won the award, Tinker AFB was forced to begin the task of converting to dual-use operations on the E-3 PDM line. That is, OC-ALC's management was challenged with making improvements to the PDM line, and re-orienting current practices to support both contract (commercial sector) and organic (public sector) operations using the same people, facilities, equipment, and information. These needs also came amidst demands to shorten PDM cycle-time and improve flexibility, responsiveness, and economy.

From a defense workforce perspective, OC-ALC is faced with the challenge of maintaining critical capabilities, knowledge, and experience amidst large reductions in force and widespread worker displacement. Thus, there is a growing need for methods and tools to minimize or avoid the loss of critical corporate knowledge and, consequently, operational readiness.

A number of factors influenced the Air Force's decision to pursue an IICE technology application demonstration effort that supports Programmed Depot Maintenance (PDM) planning and scheduling processes. First, aircraft PDM is the primary workload of OC-ALC. It is also the largest workload. Improvements to the processes supporting this workload, therefore, offers more payback potential. Further, existing systems often provide limited support in areas required to effectively plan and schedule PDM activities. Since these support processes and systems largely determine the degree to which measures of OC-ALC performance can improve, the Air Force thought that improving PDM planning and scheduling processes would yield the greatest positive impact.

PROJECT OBJECTIVES AND SCOPE

The purpose of this effort was to demonstrate the potential of the IICE technologies to facilitate simultaneous process, information, technology, and cultural change. The selected areas of

demonstration were the planning and scheduling systems supporting E-3 PDM. The following five key objectives framed the effort undertaken at OC-ALC:

1. Demonstrate ways that the IICE technologies can enhance OC-ALC personnel's capability to plan and schedule the PDM process.

2. Develop a prototype system designed to help users:

    a. reduce the overall lead time of the E-3 PDM process.

    b. improve the responsiveness of the E-3 PDM support processes.

    c. improve the accuracy of projected resource and material needs.

    d. improve the realization of promise dates.

    e. reduce the number of discrepancies during the final post-doc test.

    f. reduce the amount of unplanned, unscheduled, and over-and-above tasks in the E-3 PDM process.

    g. improve the speed and accuracy of bid package preparation.

    h. access decision support tools and existing systems so they can focus on aircraft maintenance, not information technology.

    i. enhance communication with other gateways, allowing access to technical and historical information.

    j. accurately assess the effectiveness of the IICE products with an eye toward establishing an organic capability in continuous process improvement.

3. For a select set of maintenance operations, develop an operational level process description to demonstrate how the IICE IDEF3 Process Description Capture method can be used to maintain operation-level precedence constraint information.

4. Develop a high-level simulation model of the E-3 PDM process.

5. Develop an E-3 PDM Bar-code Game Plan along with an information model and prototype database to guide the development of a system to collect shop floor actuals using bar-code technology.

Given the broad range of objectives outlined for the effort, our most difficult challenge was to establish the scope of the reengineering and development effort. That is, it was vitally important that the range of systems and processes targeted be carefully chosen to maximize positive impact while still addressing project objectives. For example, although depot maintenance includes repair and remanufacturing activities in the back shops, most of the effort's emphasis was placed

on large end-item maintenance. Therefore, items routed to the back shops were treated largely as "black-box" processes. We also identified areas where entire processes appeared to be missing, support was inadequate or entirely lacking, there was significant potential for positive impact, and leverage could be gained through cooperative effort with other initiatives.

The OC-ALC Systems Environment

Supporting today's PDM process is an extensive network of data systems that govern OC-ALC maintenance operations. In all, over thirty individual systems comprise the depot maintenance data systems network. These systems range in functional responsibility from material requirements projection to inventory tracking and maintenance operations planning to expense reporting. Each has evolved semi-independently to serve the needs of their respective communities. The cumulative result is a patchwork of old and new systems that perform a wide range of data collection, monitoring, and control activities.

Today's depot maintenance data systems struggle to meet requirements for new levels of OC-ALC infrastructure agility, responsiveness, and economy. Increasingly, the explosive rate of change to which these systems must adapt makes it difficult for OC-ALC organizations to improve their flexibility, response time, quality and reduce their costs. Among the symptoms that point to a growing gap between critical OC-ALC processes and their automated support systems are the following items.

1. **Process owners do not own their process data.** Process owners must frequently go to at least one other organization to simply gain access to data critical to their process. Having no ownership of the data, users are often forced to change code to get a different perspective of their data. For example, existing and projected material availability information is the most important resource information required by E-3 planners. This information is maintained by a separate organization and is largely unavailable to planners.

2. **Accessible data is often unusable.** Data collection systems often maintain only summary level information, rendering this information largely unusable to all but high-level management. For example, PDMSS provides a valuable summary-level projection of planned maintenance activities. Since the projection is made using high-level estimates of resource availability (e.g., material, manpower, facility) with only limited consideration of constraints, these projections are rarely useful for day-to-day scheduling and dispatching activities.

3. **Users often feel compelled to circumvent data systems.** As the pace and scope of process change accelerates, software maintenance and development backlogs (usually into months or even years); meanwhile, users devise innovative ways to apply command data systems to at least partially support activities that the systems are not designed to handle. When this occurs, data available to downstream users becomes increasingly suspect and/or unavailable. For example, E-3 planning personnel

developed an elaborate system of codes that they used to extend or change the functionality of their primary planning system, GO37E.

4. **Data systems drive the process and stifle positive change.** Policies aimed at ensuring that downstream data users get the data they require creates an environment in which data systems become the masters and the users their slaves. When this flip-flop occurs, creativity and innovation give way to subservience in satisfying data system needs at the expense of user needs. For example, GO37E calculates a critical path and generates a schedule for dispatching operations to the shop floor after planners group and link each of the operations in the E-3 planning data set. With between 9,000 and 12,000 operations typically planned for each E-3 undergoing depot maintenance, it is clearly a daunting task to study and document the relationships between each individual operation in the set. In fact, to do so puts an unnecessary strain on the range of possible schedules that can be implemented on the shop floor.

The impact of these gaps between critical OC-ALC processes and their automated support systems creates a number of problems, some of which are listed below.

1. OC-ALC performance indicators provide unreliable (even misleading) feedback and limited management visibility.

    a. Actual hour accounting, material usage, and real-time task status information is unreliable or unavailable.

    b. Shop efficiency ratings, bottlenecks in resource availability, and the lack of reliable shop floor dispatching, scheduling, and control systems combine to produce counterproductive behavior.

2. There is a general lack of integration between aircraft maintenance activities and PDM support systems and processes.

3. There is a heavy reliance on stand-alone public domain and special-purpose proprietary systems whose cost-competitiveness and functionality have been surpassed by commercial-off-the-shelf (COTS) packages.

4. Planning and scheduling of Programmed Depot Maintenance (PDM) resources is labor-intensive, time-consuming, and unreliable.

    a. There are currently no automated tools to make operation level economies visible to planners, schedulers, and supervisors. For example, lacking an explicit factory-level schedule promotes the occurrence of multiple access and button-up operations on the same panel.

    b. Currently available automation support for time-phased operations scheduling, need-date estimating, and resource contention resolution is extremely limited.

c. There is no automated support for contingency planning, analysis, and decision support.

d. There is no automated support for assessing the impact of shared facilities, equipment, personnel, and material on the PDM schedule.

e. No support is provided to improve PDM process predictability through the early identification of "over-and-above" workload (over-and-above tasks account for 20–35% of the work performed during PDM).

Production Maintenance versus Production Manufacturing

Closing the gap between critical OC-ALC processes and their automated support systems requires more than simply updating what is currently available with new technology. In fact, introducing new technology in hopes of solving problems often results in exactly the opposite result. Many correctly parrot the familiar axiom that processes and systems must be "reengineered" or "integrated" first. Only then should new automation strategies be applied. This is very true, particularly in the OC-ALC environment, where informal practice has necessarily evolved to work around an overconstrained or poorly suited system. Central to the task of reengineering is understanding the nature of the process or system to be reengineered. That is, one must first recognize those features that distinguish one environment, which is amenable to the application of one set of design principles or paradigm of operation, from another.

The OC-ALC depot maintenance environment is one that poses some subtle and unique challenges that, if overlooked, can lull process designers and system developers into choosing a systems paradigm that operates poorly, or not at all. The unique demands placed on depot maintenance planning and scheduling systems create a number of critical differences that require different strategies from those traditionally applied to the production manufacturing environment. Critical differences between the production maintenance and the production manufacturing environments require entirely different methods, processes, and systems. In spite of these critical differences, many of today's OC-ALC systems were designed and built under the assumption that the depot maintenance environment behaves just like a production manufacturing facility.

There are three distinguishing characteristics that make planning and scheduling aircraft maintenance activities uniquely different from aircraft manufacturing. First, access constraints are negligible in an aircraft manufacturing environment, whereas these constraints have a significant impact on maintenance planning and scheduling. Aircraft undergoing depot maintenance are only partially disassembled through the process, making it important to consider how to 1) protect the structural integrity of the aircraft while it is being worked on, 2) provide enough room to work, and 3) coordinate different classes of maintenance activity in the same areas. Second, in maintenance environments, only a partial ordering of activities can be developed. In the manufacturing environment, however, a firm sequence of operations can be

established since the work content is determined by the assembly requirements of the product. Finally, the bill of material is known up front in manufacturing environments, whereas it is largely unknown in a maintenance setting.

Typical of production manufacturing planning and scheduling systems, today's OC-ALC maintenance and material management systems presume that the bill of material (required for maintenance) and associated labor content can be determined beforehand (i.e., is predictable). Historical patterns at the OC-ALC, however, demonstrate that between 20% and 35% of depot maintenance work content is unpredictable or "over-and-above." Further, the prediction methods used by today's planning systems to project future spares and reprocurement needs assume that one can accurately predict future requirements by analyzing past usage. For predictable items (i.e., spare parts whose replacement rates are relatively constant), the assumption that past material patterns will closely approximate future material requirements is perfectly legitimate. However, only about 20% of the items managed by the depot material management system are considered predictable items. Fortunately, those items supply the material for most depot maintenance work (65–80% of depot workload). The remaining 80% of maintenance material items fall into the unpredictable group (see Figure 1). This means that as much as a third of all aircraft maintenance material needs are unpredictable.

As the aircraft ages, the frequency of unpredictable and over-and-above work (e.g., through the discovery of cracks and corrosion) increases, adding further complications. This phenomenon serves to both raise the OC-ALC's depot maintenance workload and increase the ratio of unpredictable to predictable work.

One consequence of this phenomenon is that schedules based on a predetermined set of tasks with a presumed duration rapidly become obsolete, often with the first discovery of over-and-above work. This is precisely the situation present in today's PDM scheduling support systems, which use a critical path algorithm to produce a schedule of depot maintenance activities. The critical path is determined by the amount of time required to perform individual operations as specified by labor standards. Calculation of the critical path also requires establishing a completely linked network of operations, or groups of operations, at the level where the critical path will be calculated. And yet, material acquisition lead time, access constraints, and resource leveling requirements—none of which are considered by the traditional critical path algorithm—determine what level of schedule compression can be achieved. In this environment, critical path-based schedules lose their utility as a plan for daily activity and, consequently, their reliability as a predictor of on-time delivery performance.

The distinction between production maintenance and production manufacturing systems became very important as the IICE team worked to provide viable solution concepts for PDM planning and scheduling.

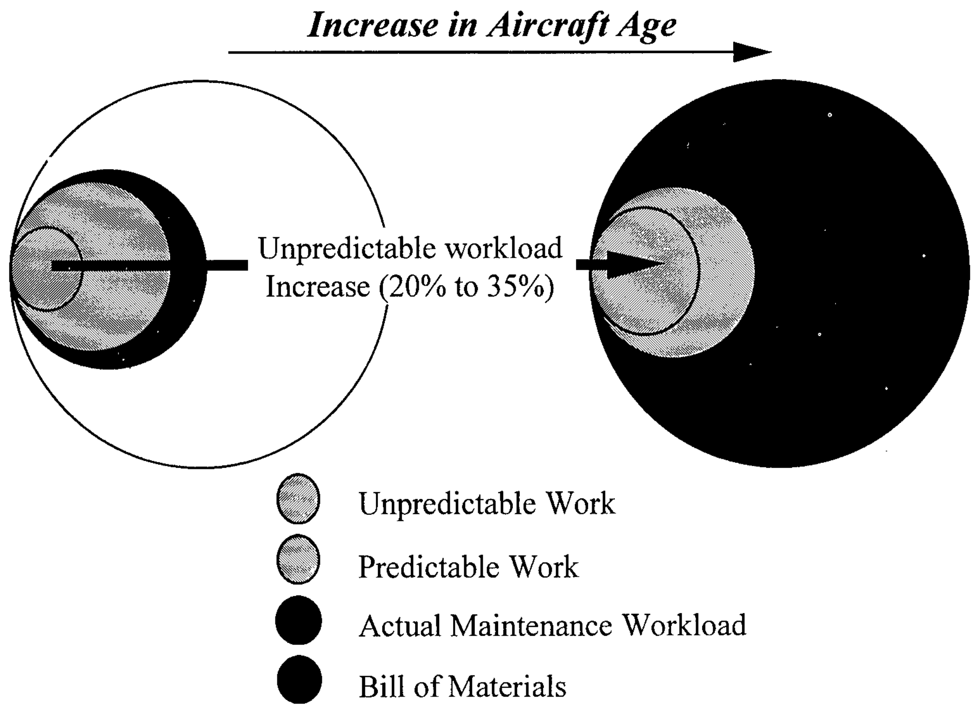


Figure 1
Unpredictable Workload Creates Requirements Computation and Scheduling Uncertainty

APPROACH

With this scope in mind, a model-driven approach to requirements definition and prototype system development was outlined (see Figure 2). Any undertaking of this kind requires the concerted effort of personnel with many different kinds of skills and experience. For this purpose alone, the IICE IDEF methods proved to be useful. Each method provided clear foundations that guided knowledge acquisition, analysis, and design activity. This also provided a common framework for information capture, organization, and communication among analysts, developers, and domain experts. More importantly, the methods provided an effective mechanism for exploring reengineering opportunities before attempting to apply automation.

This section provides a description of the approach used to investigate improvement opportunities for depot maintenance planning and scheduling. Important to the approach taken was the use of the IDEF3 Process Description Capture, IDEF5 Ontology Capture, and IDEF9 Business Constraint Discovery methods. These methods were applied together with previously developed IDEF methods (i.e., IDEFØ Function Modeling, IDEF1 Information Modeling, and IDEF1X Semantic Data Modeling methods) to support additional analysis and design decision-making activities and to demonstrate how the IICE methods complement previously developed IDEF methods.

Of the methods applied, IDEF3 and IDEF1 were most extensively used. These methods were used primarily for analysis, requirements definition, and To-Be process design. IDEF3 was used to document, analyze, and reengineer planning and scheduling processes. It was also used as the framework for a self-maintaining simulation model of the PDM process. The IDEF1 Information Modeling method was used to model the information that is currently managed to support planning, scheduling, and monitoring functions. The IDEF1X Semantic Data Modeling method was used to translate IDEF1 information management requirements into a logical database design for both the prototype planning system database and a bar-code enabled shop floor data collection database.

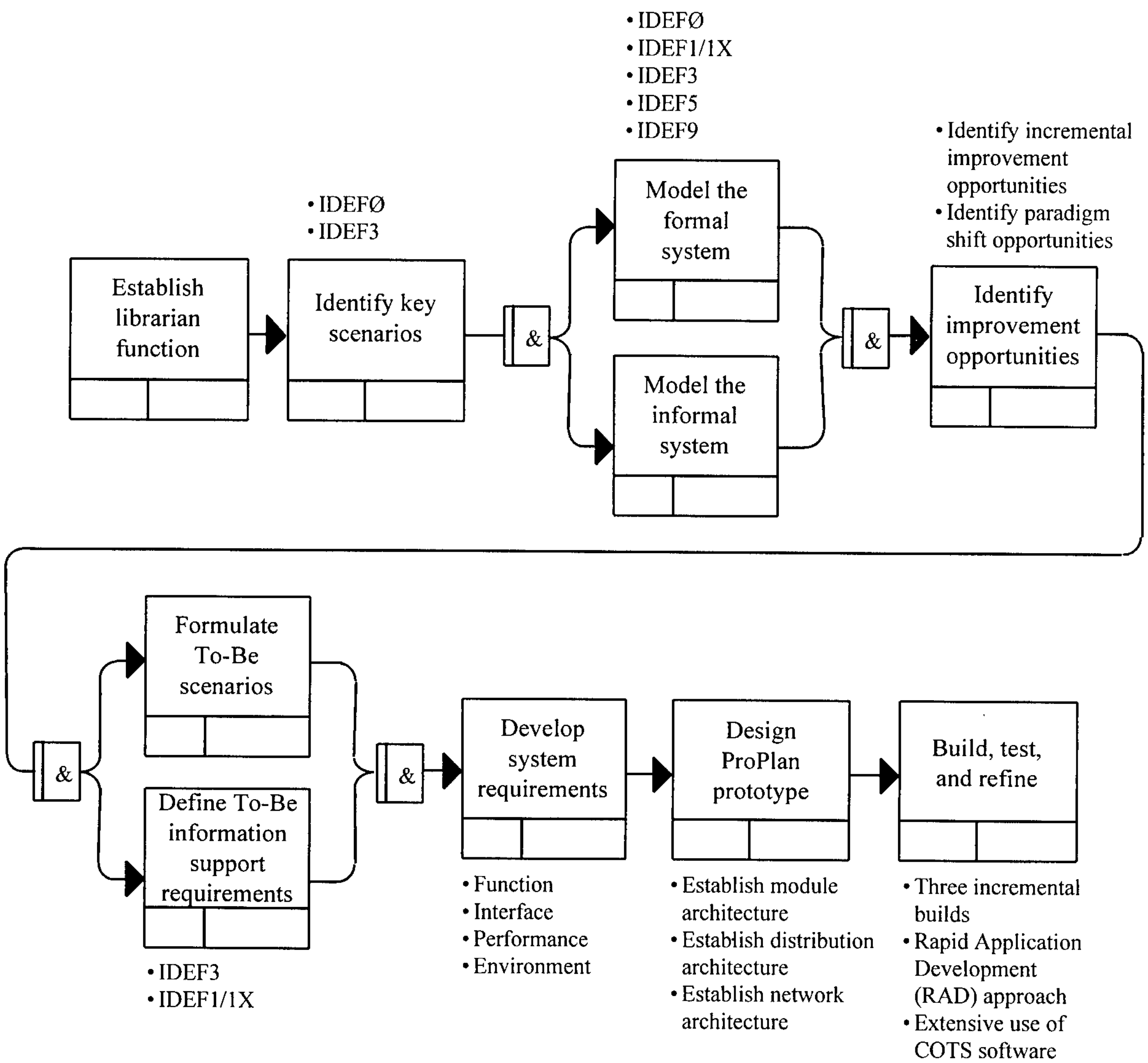


Figure 2
IDEF3 Process Description of the Technical Approach

Other IDEF methods were also applied. For example, IDEFØ was used together with IDEF3 to help scope analysis efforts. It was also used as a data collection vehicle for those situations in which timing and precedence information was unavailable. The IDEF5 Ontology Description

Capture method was also found to be quite useful (particularly during the early stages of the project) for capturing unique terminology, identifying subtle but important distinctions made by people in different role types, and uncovering key associations that could assist with downstream process reengineering and system development efforts. Of these, the most obvious manifestation of IDEF5's utility was its impact on the design of the user interface to ProPlan. By using IDEF5 to understand the key terminology used in the domain, the ProPlan user interface became easy to use. The IDEF9 Constraint Discovery method was also used. This use was largely limited to the procedure component of IDEF9 since the graphical language component of the method was under development throughout much of the project. Applying the prototype IDEF9 procedure to catalog symptoms, hypothesizing correlations to probable causes, validating those correlations, and identifying both enabling and limiting constraints helped to guide reengineering developments. For example, it was through the application of IDEF9 that the scope of the ProPlan prototype was extended to include support for E-3 work specification developers. Currently, planners and work specification developers use entirely different systems, although they must work together to effectively manage a wide range of business constraints to minimize costs while still keeping the E-3 fleet well maintained. Using the prototype IDEF9 method served to drive improvements to the IDEF9 procedure and provided a test bed for experimenting with alternative language designs.

Key Approach Elements and Innovations

A number of approach elements were used to satisfy the key objectives of this effort. These elements are shown in the following list.

1. Model-driven reengineering and application development approach involving the integrated application of multiple IDEF methods.

2. Design for the unique requirements posed by the production maintenance environment.

    a. Capture and consideration for accessibility constraints.

    b. Emphasis on maximizing planning and scheduling process flexibility and responsiveness.

    c. Explicit mechanisms to provide early notification of unplanned, unpredictable, and over-and-above maintenance requirements (e.g., electronic capture and notification of shakedown results).

3. Design for maximized reuse with particular emphasis on the following items.

    a. Maintenance requirements (i.e., work specifications, work specification tasks).

    b. Master networks.

    c. Tail-specific plans.

   d. Operations (including over-and-above operations that are not maintained by today's systems).

   e. Schedules.

   f. COTS software components.

   g. System process and information models.

4. Rapid Application Development (RAD) prototyping strategy.

   a. Use of component-based systems development environments (i.e., Digitalk parts, Visual Basic).

   b. Incremental builds (three versions).

   c. Client/server architecture.

   d. Open architecture design.

5. Finite capacity, simulation-based schedule projection and analysis.

   a. Self-maintaining operation-level E-3 PDM simulation model.

   b. Simultaneous generation of multiple, resource-constrained aircraft schedules.

   c. Elimination of the need to perform downstream resource leveling.

   d. Reduced data input burden over critical path-based methods with improved schedule projection reliability and flexibility.

   e. Ability to mimic multiple scheduling approaches and algorithms using tailorable operation induction strategies.

Each approach element was designed to facilitate a model-driven reengineering and application development approach to successfully address a highly complex set of problems, rapidly devise feasible reengineering solutions, develop automated support mechanisms embodying those reengineering solutions, and provide robust prototype systems with minimal disruption and cost.

Historical Overview

In accordance with standard IDEF modeling practice, we first established a model librarian function where source material, notes, and models were maintained for general use by the team. Project material configuration control, item check-in/check-out, review kit distribution and management, model quality management, glossary maintenance, etc., are a few of the activities performed by this function.

Based on the established project scope and working with OC-ALC personnel, we then set out to identify the key processes and recurring scenarios that comprise the planning and scheduling process. Through this activity, the events, activities, and processes that characterize both normal and exceptional situations in the E-3 PDM planning, scheduling, and execution were identified and categorized. The resulting list of scenarios was then used to further refine the initial project scope. For example, only a select set of scenarios under the *Execute* function were chosen for subsequent modeling and analysis. This list of scenarios was also used to establish data collection and analysis, and description and model development priorities.

By identifying key scenarios associated with planning and scheduling, we were also able to assess the frequency and relative importance of different parts of the process. For example, in E-3 PDM one of the most difficult, time-consuming, and error-prone processes identified was that of manually identifying and typing in the operations to be applied to individual tail numbers. These operations were based on tail-specific, work specification task call-outs. With literally thousands of operations involved, the number and frequency of transcription errors are enormous. These transcription errors force schedulers to spend hours each week poring through stacks of computer printouts to identify and resolve avoidable work stoppage problems before they happen. By simply integrating the process of associating work specification task performance requirements with task planning, this manual process was entirely eliminated.

The modeling team began by collecting and analyzing formal documentation (e.g., command data systems documentation, operating instructions, etc.) describing how the planning and scheduling systems and their associated processes were designed to operate. The formal system was then modeled using IDEF3 modeling and IDEF1/1X. Modeling of the formal system was performed iteratively and in concurrence with modeling efforts that captured informal processes.

Once the team had developed a small representative set of As-Is formal system models and a postulated set of models representing the informal process, we provided informal IDEF3 "in-context" training (i.e., training provided with material developed using actual project model data) to engage OC-ALC personnel in assisting with data collection and validation activities. This approach not only provided an effective mechanism for accelerating As-Is model development, but also served to involve OC-ALC personnel in the genesis of concurrent process and cultural change. OC-ALC personnel involvement was also critical to collect reliable time, quality, and cost data for key planning and scheduling processes. OC-ALC personnel involvement, coupled with the IDEF methods and tools, helped to ensure the success of downstream change conceptualization and simulation activities by establishing an effective mechanism to leverage the knowledge, intuition, and experience of domain experts.

Collecting descriptions of the informal system involved the identification of process activities, their inputs and outputs, the logical ordering of activity occurrence, and placement of decision points and/or branching. The IDEF3 method was used extensively for this task. The IDEF5 Ontology Capture method was useful during the initial data collection and analysis phase, where it was used to develop an understanding of the terminology associated with the planning,

scheduling, and shop floor domains. Key relationships within and between respective domains in the production maintenance enterprise were also studied by collecting and studying the associations manifested in the domain terminology base.

While modeling the relevant OC-ALC processes was generally straightforward, determining what business rules are actually supported and enforced by the information system was more difficult. Equally difficult to discern were the hidden pockets of information that constitute the "informal" information system of the enterprise. One undertakes information modeling to document both the formal and informal information system. The IDEF1 information modeling and IDEF1X data modeling methods were particularly useful for highlighting the existence and structure of the information supporting the process. The resulting models were used to establish the foundations for evaluating the As-Is information system. This evaluation focused on the adequacy and potential contribution to the management, analysis, and improvement of the process.

IDEF1/1X served predominantly in a supporting role to IDEF3, being used to display and communicate the results of information analysis rather than as a direct knowledge capture device. IDEF3 process descriptions served as the primary data collection vehicle by focusing domain expert attention on the information required to support his/her process. This approach helped to both manage information modeling activity and minimize redundant or wasteful effort.

Interview notes and representative information artifacts of the process (e.g., forms, policy manuals) were collected and catalogued by the modeling team. The initial As-Is information models were developed as function- or process-view information models typical of IDEF1/1X modeling. A "process-view information model" constitutes a projection on a comprehensive information model, displaying only those entity classes that are involved in the specific activity of interest.

This strategy helped to organize the information used or needed to support specific segments of the overall process. Likewise, for validation purposes, we wanted to avoid the common situation of forcing domain experts to pore over wall charts searching for those pieces of the model that applied only to them. This strategy also served to minimize the chance of inadvertently prescribing unnecessary information needs. By working with process-view information models, we were able to develop an unbiased snapshot of today's information systems. Once collected, individual process-view information models were integrated to construct a comprehensive information model for the To-Be system.

Once both formal and informal perspectives of the E-3 PDM planning and scheduling processes had been captured, the team set out to analyze those processes to determine what was right about them, what was wrong about them, and what could be better. Our approach involved 1) identifying process improvement opportunities, 2) formulating candidate To-Be process options, 3) exploring the feasibility and attractiveness of process improvement alternatives, 4) selecting the most viable option(s), and 5) rapid prototyping the automation support mechanisms for reengineered processes.

Including domain experts in the documentation of their processes involved them directly in thinking about how things might be done differently (or better). An interviewing strategy was used as part of a knowledge-based approach to elicit observations, intuitions, and experience from domain experts about the recurring scenarios and special-case situations encountered in their daily work activities. This interaction with both the owners and customers of the process provided additional insights (those closest to the process often develop very reliable intuitions about what can be improved and how). This process was followed by more in-depth analyses, whose purpose was primarily to support the development of To-Be process options. IDEF9-supported causal analysis was applied to those areas showing the most promise.

The main goal of causal analysis was to identify cause-and-effect chains affecting the performance, cost, and quality of a given process. An important step in causal analysis is to identify constraints between the objects and/or agents in the system. For example, the following constraints were identified for the E-3 PDM (see Table 1).

The basic process by which causal analysis is accomplished is displayed in Figure 3 below. Causal relationships take the form of either "enabling" or "limiting" constraints. Constraints encapsulate the assumptions, policies, and procedures of an organization and are key to understanding relationships between the different components of a system and the whole of which they are a part.

Candidate process improvement options were then used to formulate candidate To-Be processes. Recognition of the unique challenges posed by the production maintenance environment was key to this envisioning process. The To-Be process formulation method applied was based on fundamental business process reengineering guidelines, such as those depicted in Table 2.

The approach to To-Be process development leveraged reengineering and process improvement techniques to identify opportunities for both *incremental* and *large-scale* improvement opportunities.

Incremental improvement techniques attempt to institute positive change while maintaining the basic design of the original process. This kind of improvement strategy relies heavily on domain expert intuition and experience to streamline processes, eliminate redundant activities, and/or speed up processes through automation. This approach typically produces a 10 to 20% improvement in process efficiency. For example, in response to feedback from E-3 planners, the ProPlan system maintains planning data for low-percent operations. The planning systems currently used do not maintain this data. By simply maintaining planning data for low-percent operations, planners no longer need to regenerate operation definitions when the same low-percent operations must be performed on another aircraft. Since low-percent operations planning accounts for between 10 and 20% of the total planning workload, this simple feature in ProPlan produces a recognizably significant improvement.

Table 1. Example Constraints

Examples of Constraints Identified	Impacts
Material required to perform maintenance on a given aircraft cannot be ordered until 30 days prior to its arrival.	Procurement lead times often far exceed 30 days. Lacking the required material when the work needs to be performed causes rob backs, cannibalization, and schedule delays.
A single skill (primary skill) must be identified for each operation.	Operations defined at a level of granularity above that assigned to mechanics often call for grades that exceed what is required to perform some or most of the work specified. Hence, mechanics with lesser grades or within alternative skill categories are left idle when they could perform much or all of the work, while mechanics with the specified skill and grade level become overused.
The E-3 must share one of two paint and strip bays with other aircraft.	Schedule compression is made largely impossible due to paint bay unavailability.
Mechanic can't order material until he's taken the operation card.	Mechanics waste considerable time preparing to perform an operation only to find that in many cases the needed material is not available to perform the operation.
The only two doors large enough in the E-3 hangar to bring the aircraft in and out are accessible only to the two outside bays (of three available).	Aircraft in the middle bay can be bottlenecked by aircraft on either side of them.
E-3 operation cards are released on a schedule determined from anticipated major job durations.	The schedule does not drive shop floor maintenance activity since it does not account for over-and-above work, resource constraints, etc. Further, shop status information becomes misleading.
E-3 shop efficiencies must be maintained at acceptable levels.	Cherry picking, erroneous reporting, and the hockey-stick phenomena all occur while providing misleading information to management.

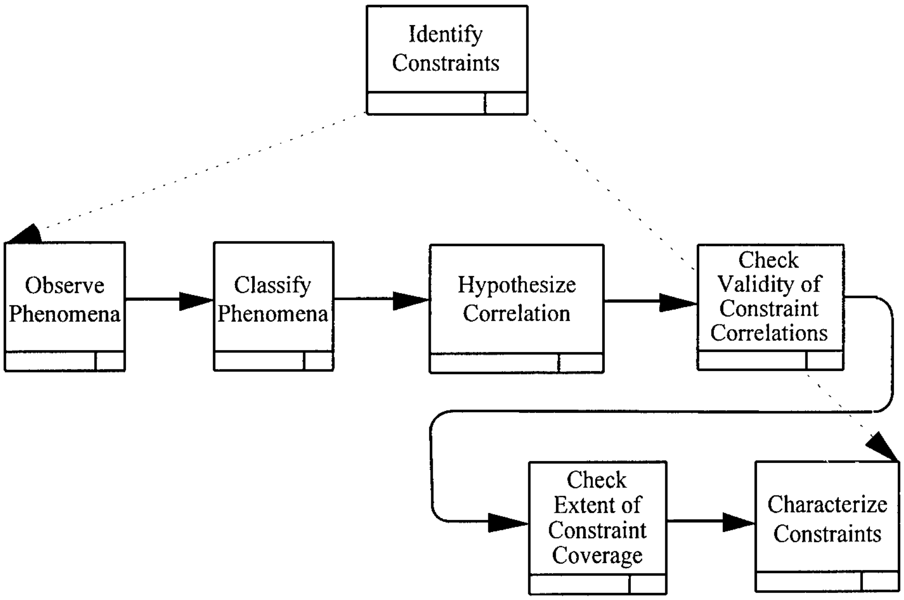


Figure 3
Identifying Constraints

Table 2. Basic Guidelines Used for To-Be Process Formulation

Organize processes around outcomes, not tasks.
Have those who use the output of the process perform the process.
Identify redundant creation, storage, and/or use of information.
Subsume information processing work into the real work that produces the information.
Capture information once, at the source.
Treat geographically dispersed resources as though they were centralized.
Link parallel activities instead of integrating their results.
Put the decision point where the work is performed, and build control into the process.
Identify portions of the As-Is process that exist to enforce constraints that are no longer applicable.
Eliminate non-value-added activities.
Simplify, consolidate, streamline, and parallelize value-added activities.

In contrast, large-scale improvement techniques seek to change the basic model of doing business. In short, these techniques search for opportunities to initiate a paradigm change that may also result in eliminating entire processes and the artifacts or products of those processes. For example, the Stochastic Resource Requirements Projector (SRRP) allows users to develop candidate schedules that automatically enforce constraints on resource availability. This capability allows for the entire elimination of downstream resource leveling activities to create a feasible schedule. The search for paradigm change opportunities requires looking outside the current realm of experience to identify comparable systems or processes that perform the same function in entirely different and innovative ways. This approach often generates order-of-magnitude improvements. The SRRP, for example, enables up to a five-fold improvement in the range of constraints that can be considered simultaneously while developing schedule projections. The SRRP also enables users to produce candidate schedules at an operation level in hours rather than weeks, as currently done.

Once alternative To-Be processes were formulated, trade-off analyses were performed to evaluate the relative merit of competing process/system design alternatives. Trade-off considerations focused on the impacts of change with respect to each of four primary areas:

1. Cycle-time performance,

2. Life-cycle cost performance,

3. Process efficiency versus flexibility, and

4. Localized versus global effects.

A prime example of the above considerations is embodied in the design approach adopted for the SRRP. One of the initial goals identified by the customer was to provide a major-job-level simulation model using the data available through the current set of OC-ALC data systems. While developing the requirements for this simulation, the processes used to develop schedule projections were documented and analyzed for potential reengineering opportunities. We soon concluded that the existing process could be improved significantly by increasing the level of detail from the major job level to the operation level while leveraging simulation technology to produce feasible schedules. In contrast to existing methods in use at OC-ALC, the reengineered process embodied in the SRRP produces only feasible schedules, thus providing more reliable PDM cycle-time performance data to decision-makers. By shortening the time it takes to develop schedule projections from weeks to hours, the SRRP-based process also provides significant life-cycle cost gains. The SRRP-based process, unlike the GO37E schedule projection process, permits planners to specify only those constraints that must be maintained among operations in a given schedule (e.g., the operation to open an access panel must precede operations performed on aircraft components physically located behind the panel). This capability promotes the development of schedules that enable agile operations capable of rapidly shifting to alternative schedule paths in response to frequent changes in known maintenance requirements. The SRRP-based process also provides increased visibility on the impacts of change to resource status on aircraft maintenance schedules or vice versa. For example, the paint bay is critical to E-3 PDM and to other aircraft PDM lines (e.g., KC-135, B-52). A change in the

scheduled availability of the paint bay can have significant impact on E-3 PDM cycle-time performance. The SRRP technology can provide rapid what-if analysis results as well as provide alternative strategies to deal with such changes.

The To-Be processes were then used to develop requirements for the prototype ProPlan system, shop floor database, and scheduling support mechanisms produced as software demonstrations for the effort. IDEF3 was used to capture a To-Be description of the E-3 PDM planning and scheduling processes. Thus, IDEF3 Process Descriptions served to define the process architecture for prototype software developments. Additional software architectures were then defined. These included function, information, module, network, and menu architectures. The function architecture was developed, in part, through the use of IDEFØ. Textual definition proved to be more time efficient for this task, however.

Information architecture development was accomplished using the IDEF1 and IDEF1X methods. These models were used to model the information necessary to support the To-Be processes and provided the framework for designing and prototyping the system database. The information model development task explored what information would be needed to monitor and control the process, what information would be used by the process, and what information would be produced by the process. Non-value-added information maintained by the As-Is information system was removed in the To-Be model. For example, many of the various codes used by E-3 planners to facilitate database-like queries on the flat file-based Workload Planning System (GO37E) were eliminated. This was made possible by providing the mechanisms to perform both predefined and *ad hoc* queries on the ProPlan database without having to rely on two-letter codes.

At the same time, the To-Be model included newly discovered information that was not used in the "As-Is," but which was deemed critical to the success of the system organization. For example, existing planning systems in use at OC-ALC maintain no information in the operation set about what facilities or special equipment is required to perform the work specified. The current system also fails to maintain information about accessibility constraints. These are both critical to capacity planning and scheduling activities. This and other value-added information was absent in the existing system but included explicitly in the developed prototypes. Module architecture definition involved allocating functions to system components. The role of this activity was to maximize reuse of COTS software to minimize development costs and reduce risk. Several COTS components were incorporated in the demonstration prototype including Microsoft Word™ (document processing), Microsoft Project™ (master schedule definition), Microsoft Excel™ (operation sorting, reporting, and spreadsheet preparation), Microsoft Access™ and Oracle™ (database), WITNESS™ (simulation), and PROSIM™ (process modeling and WITNESS code generation). The network architecture was developed informally at both a logical and physical level and was provided to OC-ALC for their use in infrastructure planning and development. Several iterations of menu architecture definition were accomplished using a rapid prototyping approach with the help of component-based software development environments. As the structure for the prototype system began to firm, the ProPlan prototype was ported to the C++ environment.

The resulting software was then demonstrated and tested incrementally by developing three versions of the software. Using feedback from the targeted user and customer communities, the development team began to incrementally narrow and refine the collection of To-Be process improvement recommendations. This turned out to be a highly repetitive process involving the incorporation of domain expert feedback into the process and prototype system design.

The most visible product developed was the prototype planning system for the E-3 PDM referred to as ProPlan. Another software product, the SRRP, was designed as an integral component to ProPlan that could be separated out as an independent environment for the E-3 PDM schedule simulation and experimentation. Working with ProPlan, the SRRP provides a self-maintaining simulation model that can be used for schedule feasibility testing and finite capacity, operation-level schedule generation. Another significant product was a prototype shop floor data collection database and shop floor information system mock-up. This product was referred to as the bar-code game plan database because it was specifically designed to leverage bar-code technology in collecting shop floor actuals. The context for use of these software products will now be discussed.

E-3 DEPOT MAINTENANCE PLANNING PROCESS

Programmed depot maintenance, basically, is a complete physical examination and partial restoration process for aircraft. Each aircraft undergoes this in-depth scheduled maintenance service every few years. Depot maintenance tends to be far more extensive in breadth and scope than field maintenance. Engineering data and maintenance data from the field assist engineers in determining both the work to be performed and the interval lengths between depot maintenance events. A team of engineers develops the initial maintenance requirements as a written document—a work specification that outlines the work requirement—and aircraft specific work orders (see Figure 4). Planners take this work specification along with applicable Technical Orders (TOs) to define work instructions (called operations and definitized lists) for the mechanic. Planners also identify the nature and composition of the resources needed to complete each operation (e.g., skills, material). Schedulers work together with production supervisors to use these work instructions in assigning start and end times for the work and to release individual work packages to mechanics. Mechanics then perform the work and provide feedback to the engineers that indicates what they found during maintenance. Engineers then take this feedback information and decide future years' maintenance requirements. This is a general description of the depot maintenance cycle—many other details have been omitted. As you can see, each group is highly dependent on the other groups to successfully perform their duties.

Engineers group similar maintenance work by programs. Three programs for the E-3 are Analytical Condition Inspections (ACI), Analytical Structural Integrity Program (ASIP), and Programmed Depot Maintenance (PDM). Within each program, a scoped task is developed by the engineers. Engineers often organize tasks by similar work content or by area on the aircraft (e.g., tasks performed on the wings, landing gear). Engineers do not determine labor hours or costs involved with their decision. Ideally, engineers only determine requirements. A definite

work breakdown structure is present in work specification construction—i.e., the program has one or more tasks, which may also be further subdivided.

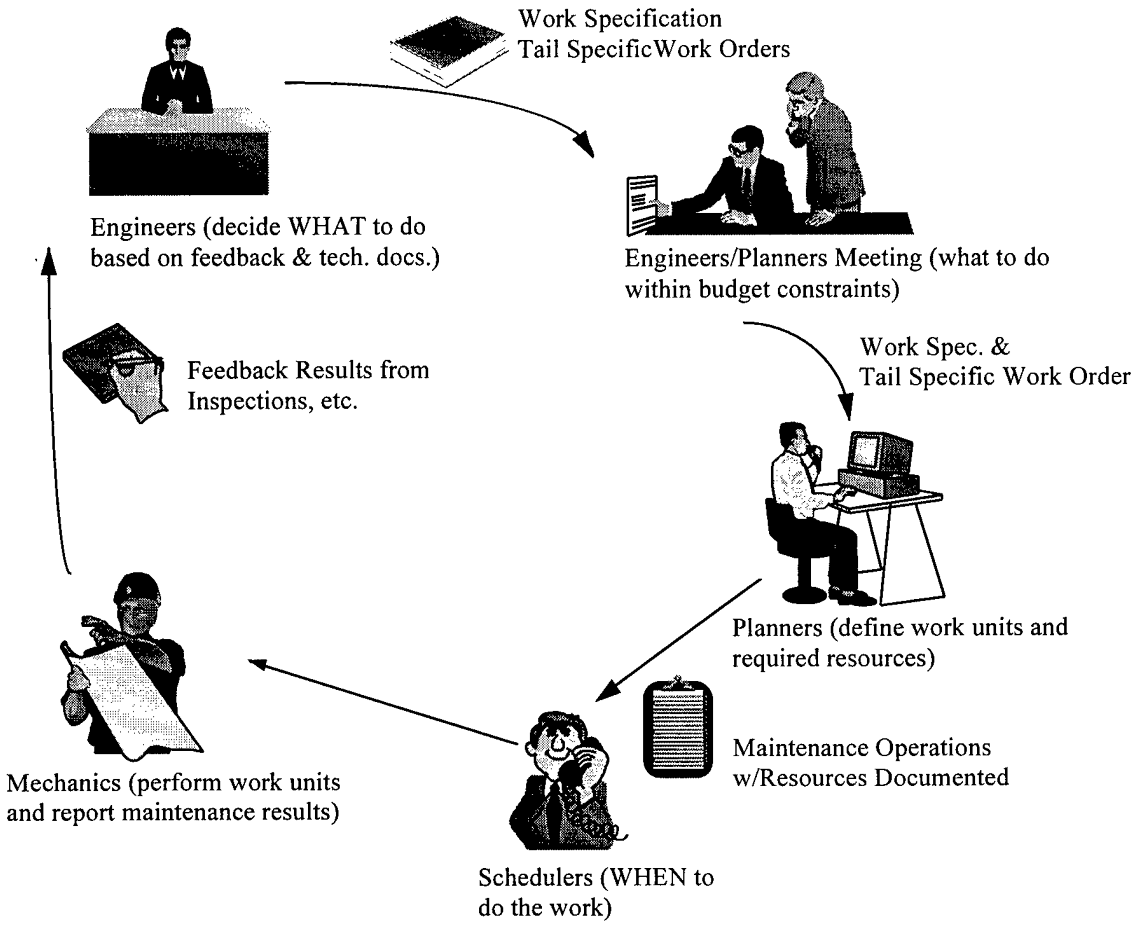


Figure 4
General Depot Maintenance Cycle

Engineers and planners then negotiate on the final maintenance requirements after feedback is obtained from planners concerning the labor hour cost for the proposed task. Labor estimates are then used to calculate the budget required for that year's depot maintenance. The final work specification is then released to planning for the maintenance work to be accomplished during that fiscal year. Accompanying the work specification is an aircraft-specific work order. The work order lists the specific required tasks to be performed on an aircraft for that fiscal year.

Planners receive this document and compare the new maintenance requirements to previous years' work specifications. Often, changes are not needed, but any different maintenance requirements need to be planned. Some tasks may change only slightly, and planners need only modify an existing task operation set to effect the changes. New modifications may require planning to create new operations to modify an existing aircraft system.

When an aircraft arrives for depot maintenance, the appropriate aircraft-specific set of work specification tasks and associated operations is selected from the generic operation set. The aircraft-specific operation set is scheduled based on precedence information supplied by planners. In scheduling and dispatching production operations, the scheduling system takes into account the current state of aircraft operation completion, precedence constraints among the operations to be performed, accessibility constraints, and current and projected resource availabilities. Production mechanics perform the operations and identify additional work units while performing maintenance inspections.

The prototype ProPlan system developed through this effort supports the roles of engineer and planner, as well as limited scheduler and mechanic functionality. The planner role is heavily supported, and the engineer is supported by assisting with the creation, modification, and reuse of work specifications and work orders. The scheduler is supported by permitting experimentation with schedules. The mechanic is supported by providing mechanisms for describing unpredictable maintenance requirements and communicating those requirements to both engineers and planners.

PROTOTYPE PROPLAN PLANNING SYSTEM

ProPlan is a prototype software system that supports the planning and scheduling of Programmed Depot Maintenance (PDM) for E-3 AWACS aircraft. It is an open architecture, client/server system with embedded COTS software that provides a single source of data for planning E-3 PDM.

The ProPlan software was developed using a Rapid Application Development (RAD) methodology incorporating user-centered design principles, multiple IDEF methods, component-based software development technologies, and a rapid prototyping strategy for end-user feedback and verification.

A predominant theme used throughout ProPlan software development was reuse. Reuse strategies were explored with respect to both the data generated and used in the environment and with respect to the software used to produce the prototype.

There were a number of opportunities identified to provide for more extensive reuse of data generated and used for planning and scheduling. For example, E-3 engineers use word processing software to write the work specifications used by planners. Included in the work specification is a work order which displays, in matrix form, which work specification tasks are to be applied to which tail numbers. Planners are then given a printed copy of the work specification and the included work order. Individual planners then design a set of operations to address each task. Before mechanics can perform the work specified, however, a planner must "tag" the generic operation set maintained within GO37E with the specific tail numbers that are to receive that work. This activity requires that the planner print out all the operations for the workload type (e.g., organic, contract, foreign aircraft, sorted by work specification task), manually highlight the tasks to be applied to the specific tail number, and then, one-by-one, "tag"

each operation in GO37E with a special code to dispatch the work. These steps could be entirely eliminated by putting the work order data into the ProPlan database and having the system automatically sort for the required operations.

Another opportunity for reuse was evidenced by the way planners worked to create each year's set of plans. E-3 planners using the current system had spent years developing a system of special codes with which they tagged planning data to permit database-style search and retrieval operations. In effect, the planners had converted the flat file systems they were using into a sort of database. They did so by first conducting a manual search across the entire operation set while concurrently tagging the data to permit automated searches in the future. This laborious work reflected their practice of data, whenever possible, making modifications to existing operations, rather than creating operations from scratch. Recognizing this, the ProPlan system was designed to support rapid search and retrieval operations by selecting search criteria from pull-down lists representing the different classes of information maintained about operations. Operations identified through this simple-to-use query strategy could then be tailored and saved as new operations. Similar examples of data reuse support could also be enumerated.

As mentioned before, reuse was also a predominant theme in the software development activity. Much of the ProPlan software is actually COTS software sewn together and integrated with C++ code. Among the COTS packages used in the software system are Microsoft's Word, Excel, Project, and Access products together with Oracle, AT&T Istel's WITNESS simulation product, and KBSI's ProCap IDEF3 support tool (see Figure 5).

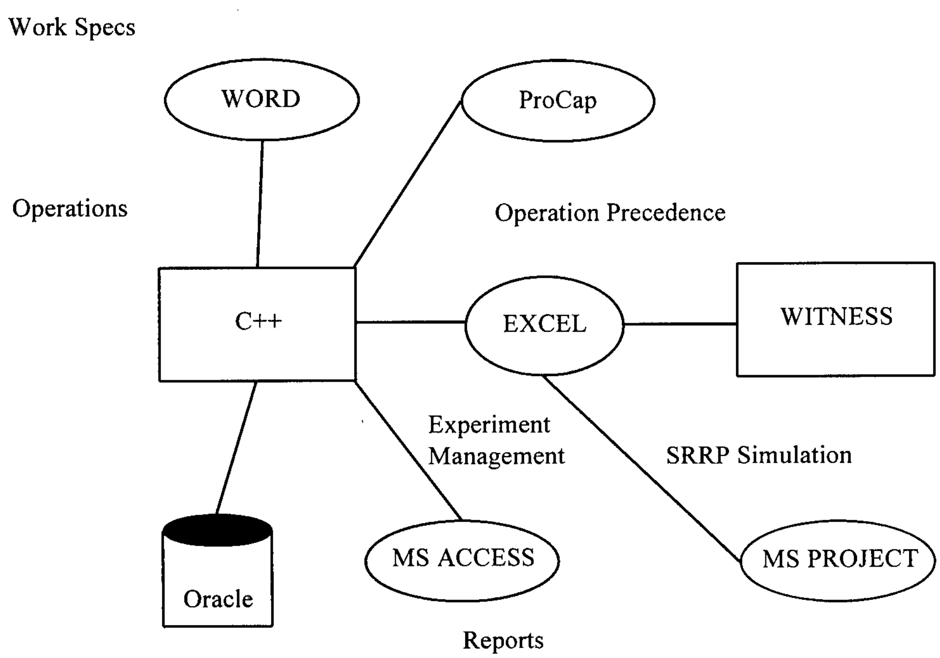


Figure 5
ProPlan COTS Components

A client/server architecture was used for the hardware/software components of the system. This architecture is composed of a single-server local area network (LAN), connecting IBM PC-compatible machines running the Microsoft Windows™ operating system (clients). An Oracle database server was used to house the data resident to ProPlan and is accessed through a Novell network. ProPlan clients were written in C++, making extensive use of COTS operating in a Microsoft Windows environment (see

Figure 6). Since ProPlan was designed to operate in a distributed environment, it includes mechanisms for concurrency control.

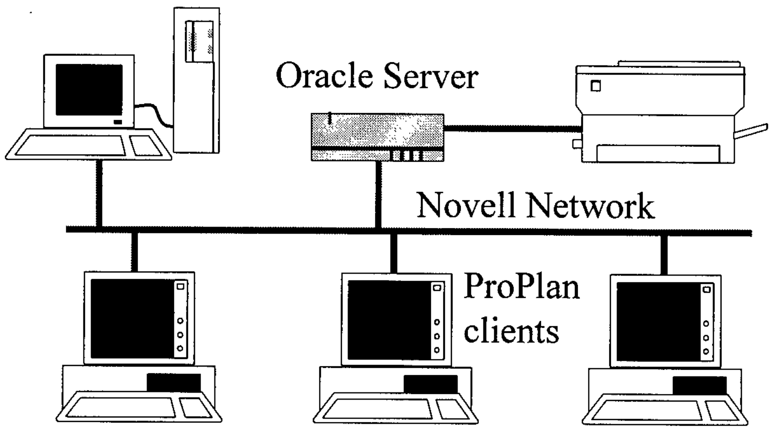


Figure 6
ProPlan Client/Server Architecture

The following includes some of the key functions supported by ProPlan.

1. Maintenance requirements management (i.e., work specification configuration control and management).

2. Assignment definition and tracking.

3. Work specification development.

4. Operation definition.

5. Resource requirements definition.

6. Depot scheduling (i.e., schedules involving all aircraft types undergoing depot maintenance).

7. Aircraft maintenance staging definition (i.e., facilities flow).

8. Major job definition.

9. Candidate schedule feasibility testing (at an operation level).

10. Finite capacity, simulation-generated scheduling (multi- or single-aircraft, operation-level schedules).

11. Capacity planning.

12. Contingency planning (i.e., what-if analysis).

The principal groups and users of ProPlan are included in the following list.

1. Planning

    a. Planning section chief

    b. Lead planner

    c. System planner

    d. Skill planner/Task planner

2. Production Support

    a. Section chief

    b. Engineer

    c. Work specification developer

    d. Project administrative official

3. Scheduling

    a. Scheduling section chief

    b. Material expediter (production control clerk)

    c. Scheduler (Expediter/Card counter)

One of the key components of ProPlan is the Stochastic Resource Requirements Projector (SRRP). The SRRP is a separable component of ProPlan that builds its own simulation model using planned operation data and resource availability data to simulate the shop floor. It can be used to evaluate planned changes to E-3 PDM or to generate candidate schedules for the shop floor. The following section provides a more detailed discussion of the SRRP.

STOCHASTIC RESOURCE REQUIREMENTS PROJECTOR

One of the original objectives of the project was to develop a major job-level simulation model of the E-3 PDM process. Like similar models developed for the OC-ALC prior to this project, this model was to be utilized in a stand-alone fashion by specially trained personnel and should answer a wide variety of what-if questions concerning labor resourcing, facility utilization, and maintenance schedule completion projections. Previous efforts modeled an aircraft flowing through a particular PDM plan depicted as a large major job network (precedence graph). This approach, while excellent for answering questions concerning the specific plan that was embedded in the model, makes it difficult to modify the model to analyze alternative plans. Likewise, the simulation models built in this way produced only course-grained results for a single aircraft maintenance line. Finally, only trained simulation modelers were able to use or modify the resulting models.

In contrast, the approach used to develop the SRRP makes it so simple to use that E-3 planners lacking simulation modeling experience can design any number of PDM plans and utilize the SRRP to evaluate those plans under the dynamics of the OC-ALC environment. Rather than the aircraft "flowing" through a particular PDM plan, the SRRP treats the plan as input to the simulator (not the aircraft). The operations then "flow" through the aircraft en route to becoming "completed" operations. This approach allows management, engineers, technicians, and mechanics to evaluate plan designs without being skilled simulation modelers. This approach also enables the simulation model to be rapidly and easily tailored enabling its use in analyzing multiple plans.

This data-driven (or black box) approach treats the simulation engine as a component that has incorporated a design robust enough to handle a wide variety of both plan sets for evaluation and situation characterizations (profiles) for experimentation.

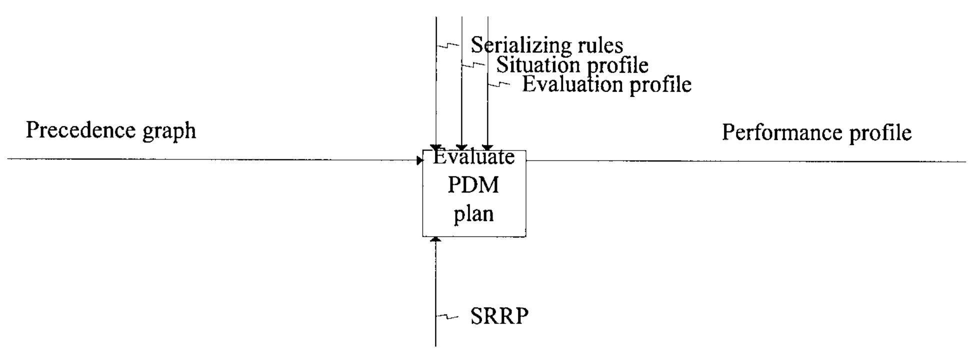


Figure 7
SRRP Data-driven Design

Based on what precedence constraints E-3 planners identify among the operations used to perform a given work specification task (assuming those constraints exist), the ProPlan environment constructs a precedence graph that is exported to the SRRP. The SRRP utilizes this input graph or graphs for multiple aircraft in conjunction with user-supplied sequencing logic, situation descriptions, and evaluation criteria to provide a detailed performance profile or report. With this information, the SRRP configures itself to produce a simulation model that accurately reflects the current (or experimental) situation (see

Figure 8). Thus, simply maintaining the operation set serves to maintain the currency and relevance of the simulation model. That is, maintenance of the E-3 PDM simulation model is a side-effect of performing normal planning functions. The SRRP also serves to support E-3 PDM process simulation at the operation level rather than simply at a major job level, effectively increasing the reliability and accuracy of the simulation model.

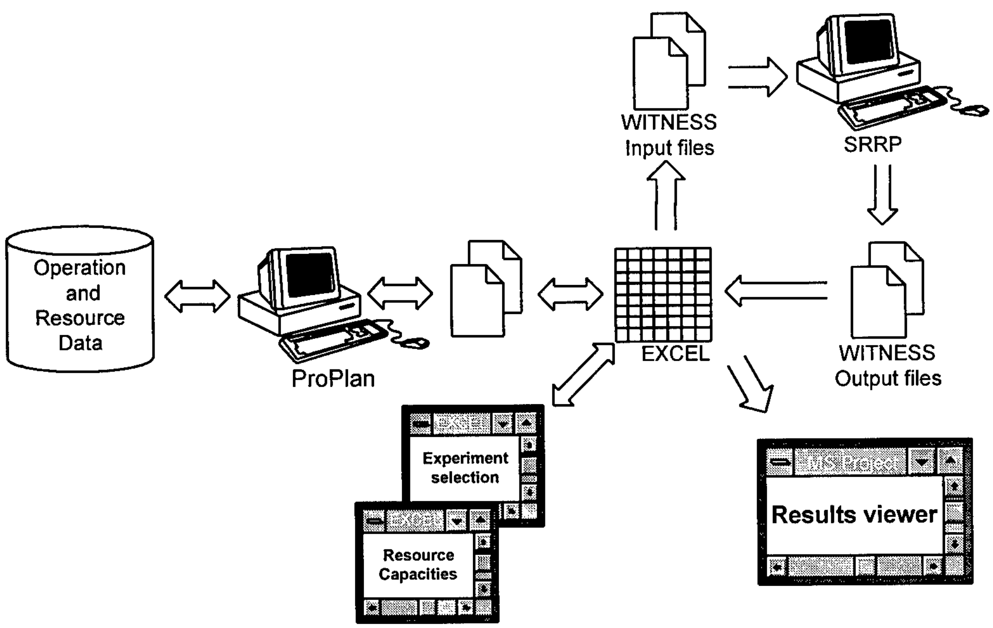


Figure 8
PDM Simulation Generation Cycle Using the SRRP

The SRRP was designed to assist the E-3 planner, scheduler, or crew chief in assessing the effectiveness of remanufacturing plans developed within the ProPlan environment. However, since the SRRP simulation was developed in the WITNESS simulation environment (copies of which are currently used and owned by OC-ALC), it may be used independently of ProPlan, if desired. The SRRP is designed to ensure its immediate application to other weapons systems.

The SRRP was developed and released in incremental builds coinciding with those of the ProPlan prototype. This ensured that the SRRP was subject to a continual update and validation cycle using data from the various weapon systems at the base. While there are many benefits to the strategy and tactics employed in its construction, the most outstanding benefit of the SRRP is its simplicity of design, thereby enabling its use by a variety of personnel over a wide array of weapon systems. The SRRP employs a "black box" approach for the simulation engine and reporting capabilities. This approach strives to achieve a "no coding required" moniker, while delivering full-featured plan evaluation to the user.

The implications of the SRRP technology are significant for the E-3 production maintenance environment. In the depot maintenance environment, the ability to respond rapidly and flexibly to newly identified maintenance requirements, material shortages, contingency situations, and so forth is of critical importance. Scheduling realignment and scheduling impact assessment today is a laborious and very time-consuming task. Proactive change management necessitates that schedules be generated rapidly using all available resource constraint information available. Since resource constraints are the most important of these, the scheduling activity must not only have access to resource-related information, but actively leverage this information as well. Scheduling development and change impact assessments can then be accomplished in real time to promote proactive, rather than reactive, depot maintenance activity. The ability to conduct what-if exercises in a simulation-based environment further improves the ability of decision-makers to plan for and predict material needs and PDM cycle-time performance.

As a finite capacity scheduling system, the SRRP uses ProPlan data provided by planners to account for a wide variety of resource constraints while testing or generating candidate production schedules. Material resource constraints are the most significant of the constraints to consider, particularly since material constraints largely determine depot maintenance cycle time. This information, however, is largely inaccessible to those engaged in the depot maintenance planning and scheduling activity. Thus, both today's scheduling systems and the SRRP rely heavily on approximations of projected material availability to develop schedule predictions. In spite of this limitation, the SRRP appears to provide the means for far more reliable schedules and schedule predictions. This is a result of its using an innovative, simulation-based approach enabling rapid candidate schedule generation that accounts for a wider range of scheduling constraints and probabilistic situations. In contrast with critical path methods, which are limited to schedule forecasting based solely on task durations, the SRRP has the ability to incorporate manpower (i.e., skills), equipment, facility, and materials constraints that often supersede the importance of task duration constraints in the development of feasible schedules. This unique capability has the potential to significantly improve the reliability and speed of depot maintenance resource planning, scheduling, prediction, and performance.

BAR-CODE GAME PLAN

OC-ALC plans to implement an actual hour accounting system (using bar-code technology) for production management to maintain an accurate picture of the shop floor status. Bar coding equipment alone, however, does not ensure reliable collection of the data needed. What is also

needed is a strategy for best utilizing the bar-coding equipment to collect the needed data and to ensure its reliability. The bar-code game plan defines a strategy for collecting shop floor data using bar-code equipment. The data that will be collected through the bar-code equipment was defined using the IDEF1X (Semantic Data Modeling) method. To identify what information was needed, interviews were conducted with representatives from the aircraft division's quality, production, engineering/planning, scheduling, contracting, finance, and competition organizations. This information was also compared with ProPlan system designs. The

requirements for data collection identified through these activities were included in an IDEF1X model. This model was then used to develop a bar-code game plan and prototype database to feed real-time status information to ProPlan.

The bar-code game plan developments included investigations of shop floor management issues. One of the prevailing misconceptions held by production management, as well as by planners, is that there should be a high degree of management exercised on maintenance operation performance to conform with tail-specific major job schedules. This notion, however, may not only be counter-productive, but impossible. For production manufacturing environments, where labor content can be specified up front, a high degree of management may be suitable. This is particularly true for highly automated manufacturing settings. Additionally, the work units developed for master schedule development, resource planning, and should-costing purposes do not necessarily reflect a structure well suited for operation-level management.

From a human factors perspective, it is also important to consider what level of management exerted over the mechanic will ensure the shop floor management systems' acceptance and success. Currently, the mechanism for shop floor management is the production supervisor. The most promising systems strategy will be one that emphasizes assisting production supervisors by helping them coordinate, prioritize, assign, and determine the current status of work within their own areas, as well as allowing them to have visibility on the status of work across the other resource centers. This conclusion is motivated by an understanding of the nature of production maintenance environments and the varying management strategies available to decision-makers. Control strategies vary depending on the process characterization of the current operating environment, as depicted in Figure 9 below.

One management strategy is the low management, low status paradigm. The current environment at OC-ALC is one of low management, low status. This is not to say that there is no management or no statusing. Maintenance processes defy attempts at close management. Where close management is exercised, it often only serves to impose constraints that further limit the flexibility and responsiveness of PDM support systems and processes. Statusing mechanisms also exist. However, these statusing mechanisms do not focus on those items that provide a true indication of the actual or projected factory state. Furthermore, the status information that is available is most often outdated or incorrect (causing decisions to be made with the wrong information) and is at too high a level of granularity to be of any significant value. The result is a highly reactive, chaotic system.

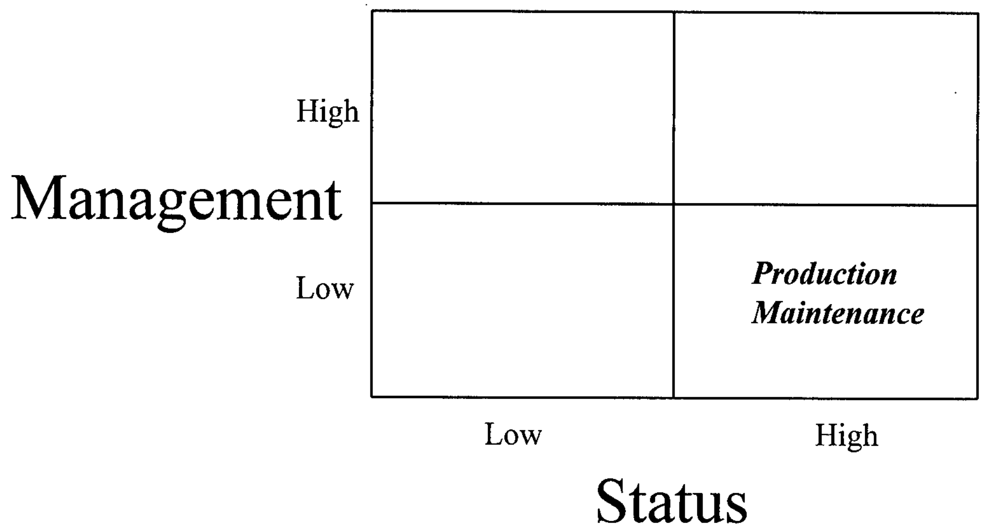


Figure 9
Management versus Status in Shop Floor Management Systems

The E-3 depot environment is one that exhibits particularly high variability in the maintenance process. The management and statusing strategy most appropriate for the depot maintenance environment is the low management/high statusing paradigm. The maintenance processes are too variable to permit high levels of management. The maintenance process inherently relies heavily on the use of people to identify and perform required maintenance tasks, and controlling people is inherently variable. Imagine a situation where operation cards for maintenance mechanics are released in a highly controlled manner. A mechanic walks up and requests an operation to do; an operation is dispensed; the mechanic performs the operation; the mechanic reports having completed the operation and requests his next assignment. Unfortunately, process variability often does not permit completion of the operation (e.g., no part is available, over-and-above work is identified). For a high degree of management to be possible, all operations would have to be ordered in precisely the way that the work will be done. Also, unpredicted operations introduce variability into the process. High management in a maintenance environment would, therefore, prove futile. High statusing, however, is possible. Currently, this is accomplished through daily coordination meetings held in the morning and afternoons between shifts. Change-over sheets provide status information to subsequent shifts, and crew chiefs and first-line supervisors regularly provide status information to production management and each other.

The bar-code game plan was devised around a low management/high statusing strategy. As such, it is specifically intended to guide the development of mechanisms to make critical indicators of current and projected status more visible to decision-makers.

PROPLAN USER TEST AND DEMONSTRATION

To provide a more realistic evaluation of ProPlan's suitability for the E-3 depot maintenance environment, a temporary link was developed between ProPlan and GO37. This link was used to conduct live user tests of ProPlan with a dummy operation set.

Planners from the E-3 planning group conducted ProPlan prototype test and evaluation activities over a two-week period. This evaluation effort included analyzing the planning functions required versus those provided in the prototype, assessing ProPlan's ease of use as compared with current planning mechanisms, evaluating the performance gains available for critical planning functions, and determining the compatibility of the prototype with legacy systems. Planners were first familiarized with both the planning paradigm supported and the mechanisms used within the prototype to support planning functions. Technology familiarization demonstrations, software training, and on-site technical advisory support was provided to support these needs. User tests were then conducted, wherein actual planners tested ProPlan using the dummy operation set to conduct sample planning activities.

Presentation of the study results included live demonstrations at OC-ALC using Air Force planners to operate the prototype system. Some of the comments made by these planners in describing ProPlan are as follows.

When asked how well ProPlan serves to provide visibility of existing resources (e.g., manpower, facilities, equipment/tools, materials), Dwight Van Meerveld, an E-3 planner, stated that ProPlan will improve the accuracy of projected resource and material needs and produce significant, measurable benefits, particularly since they do not have this capability now. Mr. Frank Cannon, another E-3 planner, noted, "During operation building or editing, we have a direct look at each item during the development of any operation. This saves going to different files for the same information."

Participating planners were also asked how effective ProPlan is in reducing the amount of time required to identify and assemble the operations to be performed on a specific aircraft. Furthermore, they were asked how good a job ProPlan does to reduce the opportunity for error in performing this planning task. Frank Cannon commented that ProPlan supported his planning activities "very well," as demonstrated by its ability to virtually eliminate the chance for error in selecting tail-specific operations. He continued, "Once the operations are assigned to a task, all that remains is for engineering to identify the requirement to a specific tail. At present, after the engineer assigns tail-specific tasks, planning must select the configuration code and work category code, and assign each to the specific tail. This is currently a time-consuming and mistake-prone process."

Planners were impressed by how well ProPlan facilitates the maintenance and continuous improvement of operation definitions. More specifically, they tested how well ProPlan supports the annual maintenance of operation set data through the use of rapid search, retrieval, and review of operations by responsible planners. Dwight found that ProPlan is "much, much better than [what] we currently use," and estimated that "maintaining operations with [ProPlan] will reduce [non-value-added] time about 20 to 40 percent." Dwight further noted that "[ProPlan's] definitized list feature will save on the order of 100 times the effort required using previous methods."

These comments are representative of those made by planners who participated in the user test. The support provided to two other key ProPlan users (i.e., engineers and schedulers) was not

tested during this phase of user testing. Since both of these roles represent key interfaces to planning, more thorough tests of ProPlan's support for these roles is recommended. ProPlan not only provides support for these role types that is largely non-existent in today's system, but it also provides a unique paradigm for integrated requirements definition, planning, and scheduling that may be coupled with a new generation of statusing systems to provide a closed-loop PDM support system solution. The primary focus of the ProPlan test, however, was on its planning support. The results of that test indicate that ProPlan helps planners do their job better, faster, and easier with increased visibility, detail, and accuracy over what is currently in use. The attitude of planners is best summarized by their section chief, Mr. Dan Mooney. When speaking of ProPlan, he simply comments, "My people want it."

Some accomplishments are reflected in Table 3. These accomplishments reflect measurable benefits that were estimated by OC-ALC based on their testing of the prototype software products of this effort.

Table 3. Goals, Metrics, and Benefits

Goal	Metric	Measurable benefits
Reduce PDM cycle time.	Cycle-time losses through duplication of effort and lost economies.	Dispatch-based schedule-simulation mechanism automatically translates planner-defined operation precedence constraints into candidate schedules that eliminate unplanned duplicate operations and maximize productive use of resources.
	Frequency of unproductive resource utilization caused by resource unavailability.	When provided with visibility of current resource status, demonstrated the ability to rapidly regenerate both operation and resource schedules to maximize productive resource utilization.
Improve responsiveness of PDM support processes.	Time to perform planning activities.	Two-day manual effort to select tail-specific operations reduced to minutes; opportunity for error reduced by an order of magnitude.
		Overnight print-check cycle required for planning data maintenance and quality assurance eliminated; improved user interface provides an additional 50% cycle time reduction for routine planning tasks.

Table 3. Goals, Metrics, and Benefits (continued)

	Time to perform what-if analyses of workload and/or schedule changes.	Cross-aircraft schedule simulation set-up time reduced from 200 man-hours to minutes; ripple effect of scheduling changes on other aircraft produced in 1 hour versus 24.
	Accuracy of schedule projections.	Finite capacity schedule generation capability that can account for all resources (the current system is only capable of considering the skill resource); extended current system's ability to perform deterministic schedule projection with a stochastic schedule simulation capability.
Reduce the number of discrepancies during the final post-dock test.	Provisions for continuous improvement of operation definitions.	Annual maintenance of operation set data supported by rapid search, retrieval, and review of operations by responsible planner; extensible, context-sensitive help facilities provide on-line mechanisms to capture and convey good operation design/redesign practice; replaced definitive list editing done "in the blind," line by line replaced with full page Microsoft Word text editing facilities.
Reduce the amount of unplanned, unscheduled, and over-and-above tasks in the PDM process.	Number and frequency of scheduler requests for planners to incorporate major jobs in tail-specific plans that were inadvertently overlooked.	Total elimination of such requests through automatic selection of tail-specific operation sets based on the Work Specification tasks called for in the work order (i.e., transcription errors eliminated).
	Percent over-and-above (O&A) operations maintained in planning system for future planning activities.	Possibly,100% maintenance of O&A operations (current system allows planners to define but not maintain O&A operation data).

SUMMARY OF ACCOMPLISHMENTS

The accomplishments of this effort are divided into two categories. The first category lists goals accomplished. The second category lists long-term goals, a representative set of candidate metrics for assessing relative progress, and some measurable benefits in terms of those metrics that may be realized through adoption and use of the demonstrated system concepts.

Some of the achieved goals are shown in the following list.

1. Demonstrated the relevance, utility, and payback potential of the IDEF3 Process Description Capture, IDEF5 Ontology Description Capture, and IDEF9 Business Constraint Discovery methods.

2. Developed the prototype ProPlan system, which is a multi-user, client/server, network application that makes extensive use of COTS software.

3. Produced a prototype E-3 shop floor database, together with a set of screens and reports characteristic of the E-3's shop floor information system needs.

4. Developed the Stochastic Resource Requirements Projector (SRRP), which provides a self-maintaining, operation-level simulation model supporting multi-aircraft, finite capacity schedule generation and testing. The SRRP demonstrated the ability to generate candidate schedules rapidly to accommodate required changes or to support contingency planning and what-if analyses in a design of experiments setting. This was one of the most significant innovations of the project.

RECOMMENDATIONS

These projected benefits can only be realized through actual implementation. Before moving forward to full implementation, however, we recommend first conducting a pilot test of ProPlan. ProPlan offers a unique set of capabilities that today's systems either do not provide or do not do well. The ProPlan prototype was used to successfully demonstrate the need for these advanced capabilities and to underscore the importance of systems designed explicitly for the production maintenance environment. Without more extensive and realistic testing, however, the ProPlan prototype cannot be adequately proven to work as intended in all planning situations.

The purpose of the pilot test effort would be to conduct a realistic, live test of the ProPlan prototype planning support system as a candidate for full implementation. As a complementary extension to the ProPlan prototype user test and demonstration effort, the pilot test would afford systems planners, developers, and researchers the opportunity of testing the long-term effects of ProPlan system implementation on PDM and PDM support process performance.

Among the tasks that would be performed as part of the pilot test are the following:

1. Debug and throughly test the ProPlan prototype.
2. Validate the SRRP simulation-based approach for schedule testing and generation.
3. Implement and operate the ProPlan pilot system parallel to existing systems.
4. Monitor the performance of ProPlan (particularly in anomalous situations).
5. Determine what changes, if any, would be required to support ProPlan implementation across PDM lines.
6. Maintain currency of the ProPlan models and a log of lessons learned to support future implementation activities.

(THIS PAGE INTENTIONALLY LEFT BLANK)

SUMMARY

The IICE technology demonstration effort conducted at OC-ALC produced a prototype planning system (ProPlan) that embodies a wide range of process improvements. These process improvements were identified through the application of the IICE IDEF3 Process Description Capture and IDEF5 Ontology Description Capture methods. The improvements identified using these methods were used to drive the prototype development effort. For example, planners currently select the operations to be applied to a specific aircraft manually and then transcribe those selections to the dispatching component of GO37E. ProPlan could shorten this two-day effort to minutes and reduces the potential for error. In addition to saving planners time and effort, this feature of ProPlan could entirely eliminate the need for schedulers to check the thousands of operations dispatched to the shop floor for any operations that may have been inadvertently left out. Another product of the effort was the Stochastic Resource Requirements Projector (SRRP). This tool uses planning data in ProPlan to produce an operation-level simulation model supporting multi-aircraft, finite capacity schedule generation, and testing. If implemented with ProPlan, the SRRP could be used to generate candidate operation-level schedules, to support contingency planning, and to conduct what-if analyses.

The IICE methods provided an efficient means to successfully demonstrate a model-driven approach to systems analysis, design, and development. IDEF3 proved its versatility and power as a process description capture mechanism. IDEF5 and IDEF1 were also used, providing important insights on domain-specific terminology, experience-based knowledge, and information sharing needs among planners, schedulers, and maintenance technicians. Although used in a relatively formative stage, IDEF9 helped the contractor team identify business constraints that impacted planning activities (e.g., material acquisition constraints). These methods were used in a model-driven, rapid application development approach to produce the ProPlan prototype. The technology used to support this approach included IDEF modeling tools, component-based software development environments, client/server technology, and a number of COTS software components.

Ultimately, however, the full benefit of these technological solutions could only be realized by carrying the work that was begun toward full implementation. For many routine planning activities, ProPlan could provide a 50% reduction in the time and effort required of planners. ProPlan also provides extensive database storage, search, and retrieval capabilities enabling maximized reuse of previously developed planning data. This feature could reduce planning workload as much as 10 to 20% by eliminating the need to recreate plans for low-percent operations. Noting these and other benefits of a ProPlan solution, implementing ProPlan could improve the speed, reliability, and ease with which planning tasks are performed.

Before moving forward to full implementation at OC-ALC, however, we recommend first conducting a pilot test of ProPlan. Pilot testing would be used to examine the ProPlan prototype in a realistic setting as it is applied to the full range of planning situations. Pilot testing would also provide the data needed to determine ProPlan's true payback potential at both the planning and PDM levels.

U.S. GOVERNMENT PRINTING OFFICE 1996 549-073/40027